(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
8 November 2001 (08.11.2001)

PCT

(10) International Publication Number
WO 01/84609 A1

(51) International Patent Classification[7]: H01L 21/28

(21) International Application Number: PCT/US01/40633

(22) International Filing Date: 30 April 2001 (30.04.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/201,113 2 May 2000 (02.05.2000) US

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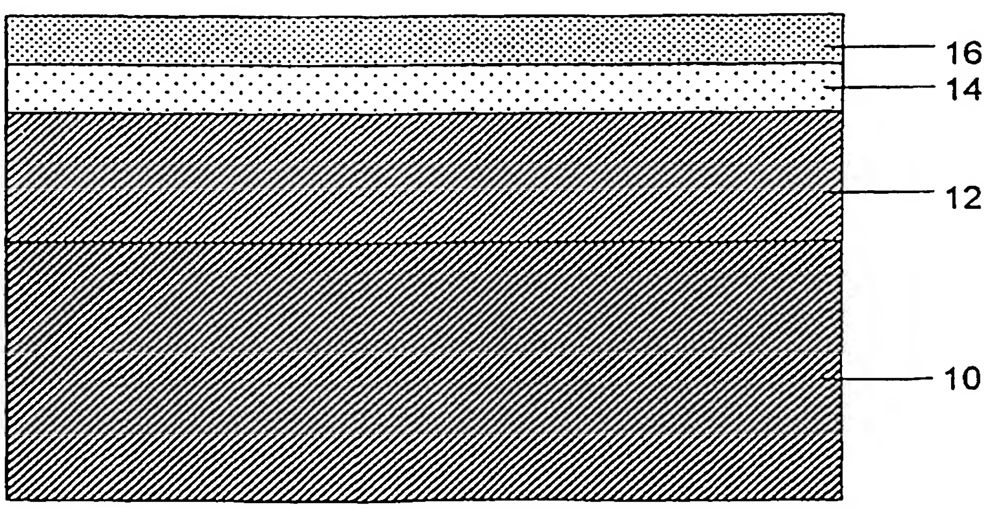
(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD FOR LOW TEMPERATURE FORMATION OF STABLE OHMIC CONTACTS TO SILICON CARBIDE



WO 01/84609 A1

(57) Abstract: A method for forming ohmic contacts on a silicon carbide substrate (10, 12) is provided. The method includes the steps of providing amorphous silicon and forming an amorphous silicon layer (14) on a silicon carbide substrate (10, 12). A metal layer (16) is formed on the amorphous silicon layer (14) and the resulting structure is annealed to create a metal silicide layer (18) on the silicon carbide substrate (10, 12). A silicon carbide ohmic contact is also provided.

METHOD FOR LOW TEMPERATURE FORMATION OF STABLE OHMIC CONTACTS TO SILICON CARBIDE

Cross Reference to Related Applications

This application claims the benefit of U.S. Provisional Application 60/201,113 filed on May 2, 2000.

Background of the Invention

Field of the Invention

This invention relates to electrical contact structures used on semiconductors, and more particularly, an improved method for forming stable ohmic contacts to silicon carbide.

Description of the Related Art

Silicon carbide is known in the art to be an excellent semiconductor material for use in harsh environments, particularly in high temperatures. However, in order to be useful in such environments, the materials used for ohmic contacts on a silicon carbide semiconductor must also be able to withstand such extremes. Ohmic contacts are contacts which have a negligible resistance regardless of the polarity of the applied voltage and are used to make connections between the semiconductor and the other devices in an electronic system.

Many of the traditional materials used to make ohmic contacts react with silicon carbide at high temperatures, causing compounds to form that undesirably increase electrical resistivity. It has been found that refractory metal silicides

are thermodynamically stable with silicon carbide at high temperatures and are thus optimum ohmic contact materials for silicon carbide. These refractory metal silicides are binary compounds which include silicon and a metal such as nickel, titanium, tungsten, cobalt, molybdenum or tantalum. As the ternary phase diagram of FIGURE 1 illustrates, nickel silicide ($NiSi_2$) is stable when in contact with silicon carbide (SiC) at a temperature of 900°C. Thus, the thermodynamic stability of the structure is evident. Similar phase diagrams, and thus similar thermodynamic stability, exist for the other refractory metal silicides as well.

The process of forming metal silicide ohmic contacts on silicon carbide poses substantial problems. For example, U.S. Patent Nos. 5,442,200 and 5,980,265, both issued to Tischler, describe the formation of a metal silicide ohmic contact for silicon carbide. The process disclosed involves forming a crystalline silicon layer on the silicon carbide, providing a contact metal layer on the crystalline silicon layer and annealing the resulting article at a temperature from 900°C to 1100°C to form the metal silicide on the silicon carbide substrate. However, these elevated annealing temperatures may be detrimental to certain silicon carbide devices, particularly where shallow junctions exist. The elevated temperature annealing may also lead to chemical reactions elsewhere in the device. High temperature processes also lead to an increase in the interfacial traps between the oxide and the SiC in a metal-oxide-semiconductor (MOS) device.

Studies of other metal silicide contacts have been made, such as cobalt silicide. Once again, though, annealing at a high temperature (900°C) is required, producing the same detrimental effects as the process described above.

Lower temperature processes have also been investigated, such as the co-sputtering of titanium silicide ($TiSi_2$) or tungsten silicide (WSi_2) on a silicon carbide substrate. However, precision of the correct ratio of silicon to the metal is difficult to obtain using this process, which may lead to an excess of either silicon or the metal. An excess of silicon leads to the formation of silicon precipitates, increasing electric resistance. An excess of metal will lead to a reaction with the silicon carbide substrate, again undesirably increasing electric resistance. In addition, sputtered tungsten silicide is amorphous and must be annealed at a temperature of 1050°C in order to crystallize, whereupon it may shrink about 25%. The amorphous characteristic of the tungsten silicide is indicative that other metal silicides formed by sputtering may be amorphous as well, leading to the necessity of high temperature crystallization and resulting shrinkage. High temperature crystallation creates the same detriments as the high annealing temperatures described above. Further, if high temperature crystallation is not performed for an amorphous metal silicide, the silicide will be in a metastable state. In such a state, exposure to high temperatures during use may crystallize the silicide, causing it to shrink and separate from the silicon carbide substrate or crack, thus damaging or destroying the contact.

Accordingly, it is desirable to improve the method for forming stable ohmic contacts to silicon carbide and provide a method which would overcome the foregoing difficulties by involving lower processing temperatures.

Summary of the Invention

According to the present invention, an improved method for forming ohmic contacts on a silicon carbide substrate is provided. A silicon layer and a metal layer are formed on the silicon carbide substrate and annealed to create a metal silicide layer on the substrate. The improvement includes providing amorphous silicon for formation of the silicide layer.

In accordance with another aspect of the present invention, a method of forming ohmic contacts on a silicon carbide substrate is provided. The method includes the steps of providing amorphous silicon and forming an amorphous silicon layer on a silicon carbide substrate. A metal layer is formed on the amorphous silicon layer and the resulting structure is annealed.

In accordance with yet another aspect of the present invention, a silicon carbide ohmic contact is provided. The contact includes a silicon carbide substrate and an ohmic contact layer proximate to the substrate. The ohmic contact layer includes amorphous silicon and a metal selected from the group consisting of nickel, titanium, tungsten, cobalt, molybdenum and tantalum.

One advantage of the present invention is the provision of amorphous silicon in the formation of an ohmic contact, thereby allowing reduced annealing temperature.

Another advantage of the present invention is the reduction of the required annealing temperature for an ohmic contact, thereby reducing temperature-related defects in the resulting structure.

Still other benefits and advantages of the invention will become apparent to those skilled in the art upon reading and understanding the following detailed description.

Brief Description of the Drawings

The invention may take form in certain steps or arrangements of steps, or in certain components or arrangements of components, preferred embodiments of which will be illustrated in the accompanying drawings wherein:

FIGURE 1 is a ternary phase diagram of silicon, carbon and nickel at 900°C;

FIGURE 2 is a schematic representation of one embodiment in accordance with the present invention;

FIGURE 3 is a schematic representation of another embodiment in accordance with the present invention;

FIGURE 4 is a photomicrograph of the microstructure of one embodiment in accordance with the present invention; and

FIGURE 5 is a photograph of the microstructure of another embodiment in accordance with the present invention.

Detailed Description of the Preferred Embodiments

Referring now to the drawings, wherein the showings are for purposes of illustrating preferred embodiments of the invention only and not for purposes of limiting the same, FIGURE 2 illustrates the formation of an ohmic contact of the present invention. A silicon carbide (SiC) substrate **10** may include a portion **12** which is doped as may be dictated by a particular application according to methods known in the art. The silicon carbide substrate **10** may be a wafer or an epilayer deposited on a suitable material, such as silicon. A layer of amorphous silicon **14** is applied to the silicon carbide substrate and a layer of metal **16** is formed on the silicon layer **14**. The entire structure is annealed, resulting in the structure illustrated in FIGURE 3.

Turning now to FIGURE 3, the silicon carbide substrate **10** and any doped portion **12** are now proximate to a complete ohmic contact layer **18**. During the annealing portion of the process, the metal layer **16** (referring back to FIGURE 2) diffuses into the silicon layer **14** (also referring back to FIGURE 2), thus creating a metallic silicide layer **18** as the ohmic contact.

Processes of the prior art have used crystalline silicon for the silicon layer **14**. As a result, high temperature annealing in the range of 900°C to 1100°C has been necessary to cause the metal layer **16** and the silicon layer **14** to diffuse and form the metallic silicide layer **18**. Such high temperature annealing may be detrimental to the resulting semiconductor, particularly where any shallow junctions and oxide/silicon carbide interfaces are critical.

The present invention overcomes the problems of the prior art by providing amorphous silicon for the silicon layer **14**. Amorphous silicon reacts with some metals at lower temperatures than crystalline silicon. It is anticipated that a range of refractory metals may be used for the metal layer **16**, e.g., nickel, titanium, tungsten, cobalt, molybdenum or tantalum. However, nickel and titanium are particularly preferred. It has been found that nickel will react with amorphous silicon at low temperatures, particularly in the range of 200°C to 360°C, to form nickel silicide ($NiSi_2$). It has also been found that titanium readily reacts with amorphous silicon at low temperatures to form titanium silicide ($TiSi_2$). Use of the amorphous silicon with a selected metal results in the formation of a crystalline silicide which is stable against volume changes caused by changes in temperature. As a result, high-temperature crystallization is not required, thus allowing a thermodynamically stable device requiring no detrimental high-temperature processing to be produced.

The details of the present invention will be understood more clearly with the following examples.

Example 1

A 3C-SiC substrate was created by depositing SiC epilayers on silicon. A 2μm thick layer of amorphous silicon was deposited on top of the 3C-SiC substrate by low pressure chemical vapor deposition at 550°C. A 600nm layer of nickel was sputtered on top of the amorphous silicon layer. The resulting structure was annealed at 300°C for eighteen hours in a nitrogen

atmosphere. The microstructure of the resulting nickel silicide ($NiSi_2$) layer is shown in the photomicrograph of FIGURE 4. An excess of amorphous silicon is present in the embodiment shown in FIGURE 4, reflecting early results. The presence of $NiSi_2$ was confirmed by energy dispersive x-ray spectroscopy and by electron diffraction. The resulting $NiSi_2$ layer was approximately 0.25μm thick, which is a suitable thickness for an ohmic contact layer for a silicon carbide device.

Example 2

An SiC substrate was created by depositing SiC epilayers on silicon. A 100nm thick layer of amorphous silicon was deposited on top of the SiC substrate by low pressure chemical vapor deposition. A 33nm thick layer of nickel was sputtered on the amorphous silicon layer. The resulting film was reacted at 300°C for 12 hours in a nitrogen atmosphere. FIGURE 5 is a photomicrograph of the $NiSi_2$ film on the SiC epilayer, demonstrating the capability of device metallization.

The ohmic contact layer does not need be of specific thickness, but for appropriate stoichiometry (to form $NiSi_2$), it is recommended that the amorphous silicon layer be 3.3 times the nickel layer thickness.

Using a silicon carbide of a 3C-SiC epilayer deposited upon silicon, specific contact resistances with nickel silicide contacts of the present invention have been measured, yielding a resistance between 3.5×10^{-5} and 3.0×10^{-3} ohm cm^2. It is anticipated that SiC epilayers deposited upon other suitable

substrates may be used, as well as silicon carbide wafers instead of epilayer-type silicon carbide. In addition, silicon carbide wafers with appropriately doped epilayers may be employed with a metal silicide ohmic contact of the present invention, resulting in an anticipated improvement in resistance.

Similar procedures and comparable resulting structures are anticipated for other refractory metals which react with amorphous silicon at relatively low processing temperatures. In order to provide an optimum dispersion of the metal in the amorphous silicon, excess metal may be deposited onto the amorphous silicon layer and the annealing step of the process will last until the amorphous silicon layer is completely consumed. The excess metal can then be etched away.

The use of amorphous silicon and the resulting reduction of process temperatures from the range of 900°C- 1100°C to a range of 200°C-360°C is greatly beneficial to the stability of the silicon carbide device. Damage and detrimental effects often caused to the ohmic contacts by the higher process temperatures are avoided, creating an improved silicon carbide semiconductor.

The invention has been described with reference to the preferred embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

Having thus described the invention, what is claimed is:

1. In a method for forming ohmic contacts on a silicon carbide substrate, wherein a silicon layer and a metal layer are formed on the silicon carbide substrate and annealed to create a metal silicide layer on the silicon carbide substrate, the improvement comprising:

providing an amorphous silicon for formation of the silicide layer.

2. The improvement according to claim 1, wherein the step of annealing is performed at a temperature in the range of about 200 degrees Celsius to about 360 degrees Celsius.

3. The improvement according to claim 2, wherein the step of annealing is performed at a temperature of about 300 degrees Celsius.

4. The improvement according to claim 3, wherein the step of annealing is for a time from about twelve to eighteen hours.

5. The improvement according to claim 1, further comprising:

providing a metal selected from the group consisting of nickel, titanium, tungsten, cobalt, molybdenum and tantalum for formation of the metal layer.

6. The improvement according to claim 1, wherein the step of forming a silicon layer includes depositing amorphous silicon on the substrate by low-pressure chemical vapor deposition.

7. The improvement according to claim 6, wherein the step of depositing amorphous silicon is performed at a temperature of about 550 degrees Celsius.

8. The improvement according to claim 1, wherein the step of forming a metal layer includes sputtering the metal layer on top of the amorphous silicon layer.

9. The improvement according to claim 1, wherein excess metal is deposited onto the amorphous silicon and the excess metal is etched away after annealing.

10. A method for forming ohmic contacts on a silicon carbide substrate, comprising the steps of:

providing amorphous silicon;

forming an amorphous silicon layer on the silicon carbide substrate;

forming a metal layer on the amorphous silicon layer; and

annealing the resulting structure.

11. The method for forming ohmic contacts of claim 10, wherein the step of annealing is performed at a temperature in the range of about 200 degrees Celsius to about 360 degrees Celsius.

12. The method for forming ohmic contacts of claim 11, wherein the step of annealing is performed at a temperature of about 300 degrees Celsius.

13. The method for forming ohmic contacts of claim 12, wherein the step of annealing is for a time from about twelve to eighteen hours.

14. The method for forming ohmic contacts of claim 10, the method further comprising:

providing a metal selected from the group consisting of nickel, tungsten, titanium, cobalt, molybdenum and tantalum for the formation of the metal layer.

15. The method for forming ohmic contacts of claim 10, wherein the step of forming an amorphous silicon layer includes depositing amorphous silicon on the substrate by low-pressure chemical vapor deposition.

16. The method for forming ohmic contacts of claim 15, wherein the step of depositing amorphous silicon on the substrate is performed at a temperature of about 550 degrees Celsius.

17. The method for forming ohmic contacts of claim 10, wherein the step of forming a metal layer includes sputtering the metal layer on top of the amorphous silicon layer.

18. The method for forming an ohmic contact of claim 10, wherein excess metal is deposited onto the amorphous silicon and the excess metal is etched away after annealing.

19. A silicon carbide ohmic contact, comprising:

a silicon carbide substrate;

an ohmic contact layer proximate to the silicon carbide substrate;

the ohmic contact layer including amorphous silicon and a metal selected from the group consisting of nickel, titanium, tungsten, cobalt, molybdenum and tantalum.

20. The silicon carbide ohmic contact of claim 19, wherein the ohmic contact layer is about 0.25μm thick.

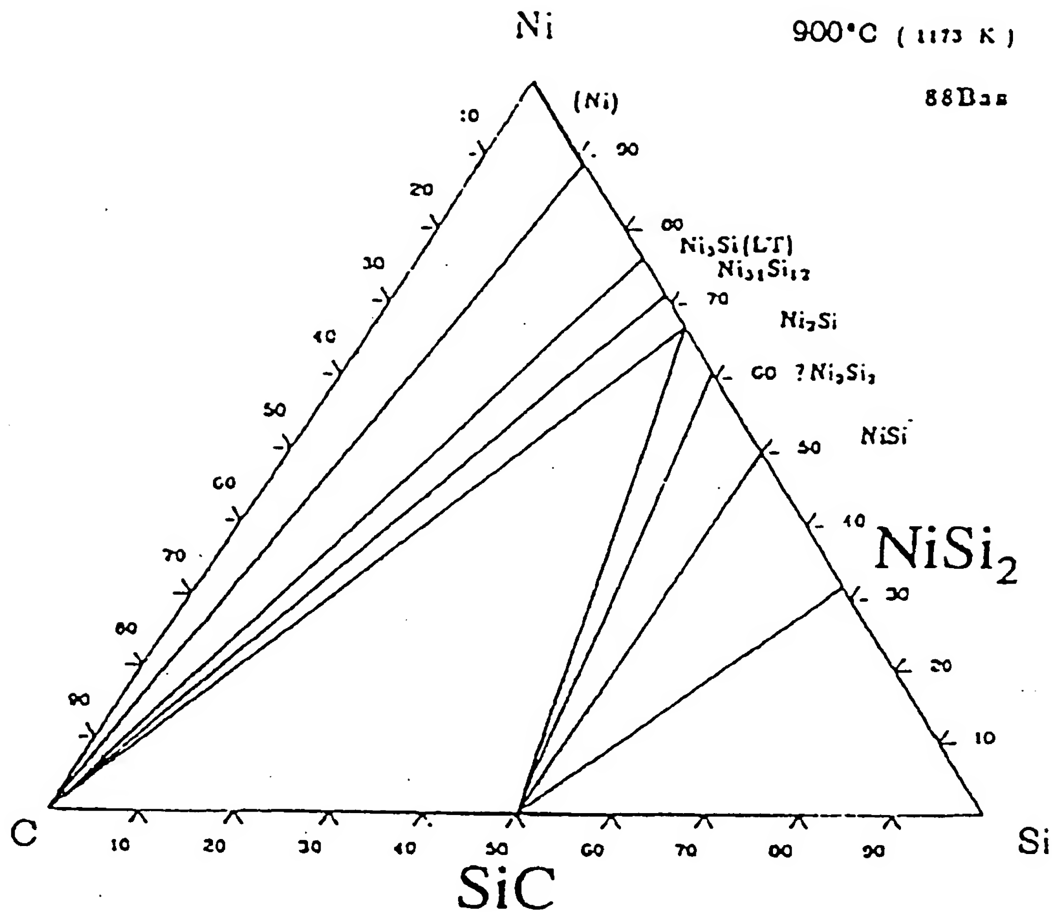

Ni
900°C (1173 K)
88Bas
(Ni)
Ni3Si(LT)
Ni31Si12
Ni2Si
?Ni3Si2
NiSi
NiSi2
C
SiC
Si

FIG. 1

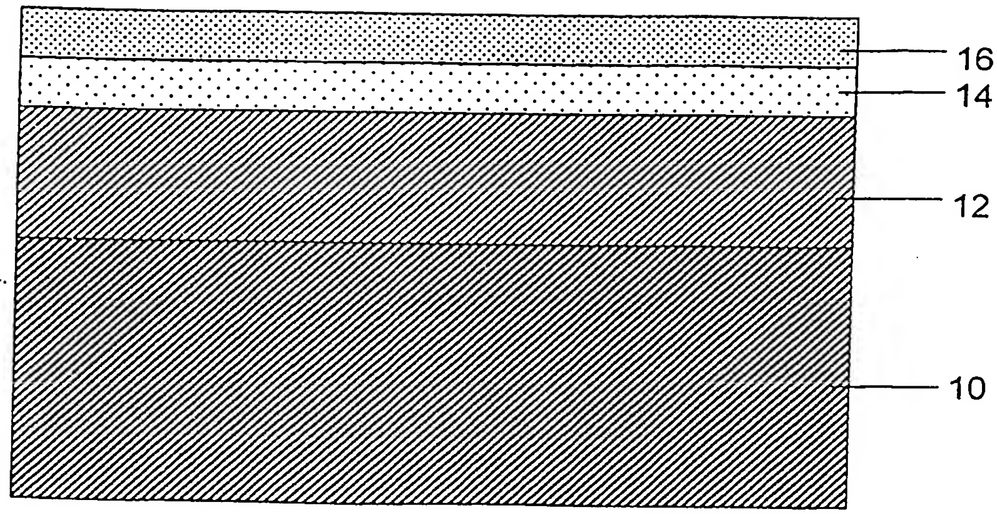


FIG. 2

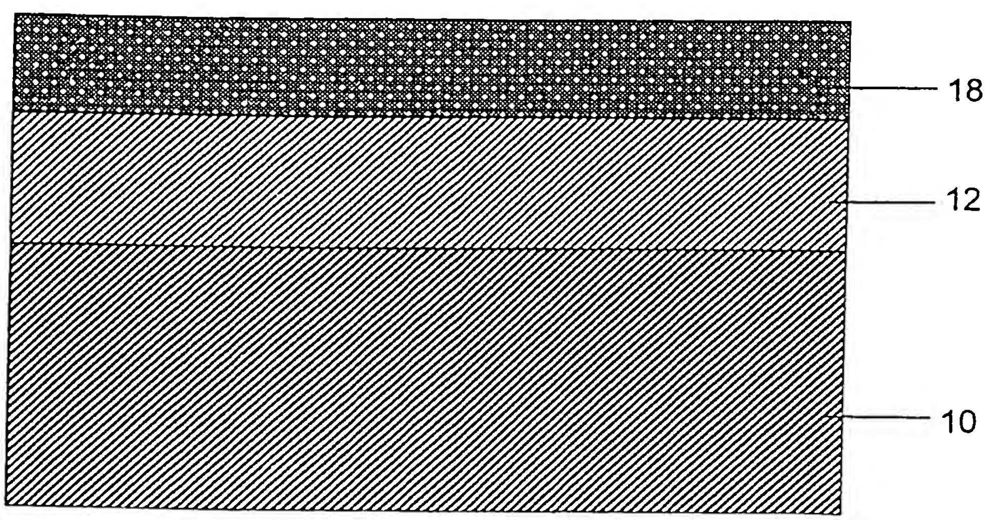


FIG. 3

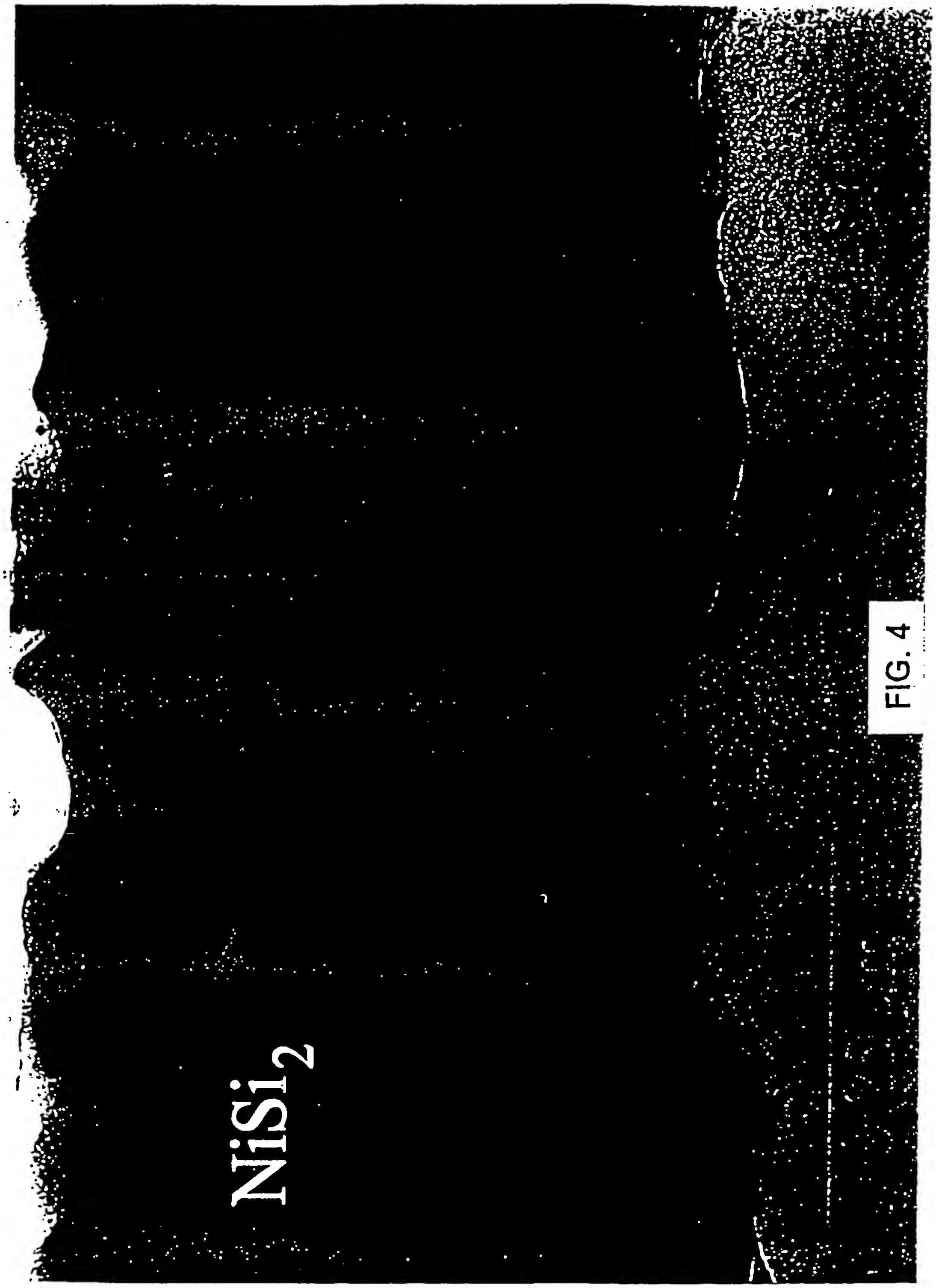


FIG. 4

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/40633

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) :H01L 21/28
US CL : 438/602, 660, 931; 257/77
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 438/602, 660, 931; 257/77, 78

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US 5,442,200 A (Tischler) 15 August 1995 (15.08.1995), Figs. 1A-2D; col. 6, line 26- col. 10, line 50.	1-3, 5-12, 14-20 ----- 4, 13
Y	US 5,502,003 (Ogino et al.) 26 March 1996 (26.03.1996), Figs. 9 & 10; col. 2, line 55- col. 4, line 31.	1-20
Y	JP 8-64800 A (Kawase et al.) August 1996 - Figs. 1-9.	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 JUNE 2001	17 JUL 2001

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Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/40633

B. FIELDS SEARCHED
Electronic data bases consulted (Name of data base and where practicable terms used):

JPO, EPO, USPAT, DERWENT, US-PGPUB

search terms: silicide, salicide, silicon carbide Si-C SiC, amorpphous silicon, titanuim Ti, cobalt Co, nickel Ni, taltanum Ta, molybdium Mo, low pressure chemical vapor deposition LPCVD, heating annealing, temperature, hour second minute, ohmic contact